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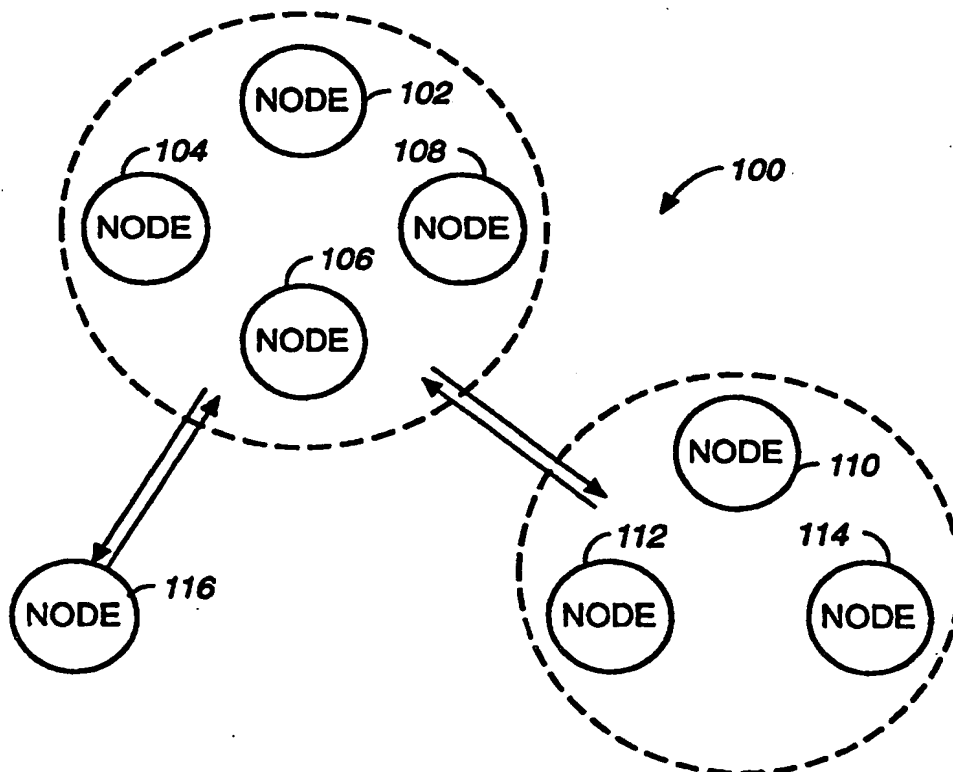
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(54) Title: FREQUENCY HOPPING MEDIUM ACCESS CONTROL PROTOCOL

(57) Abstract

The communication system (100) is directed to providing frequency hopping medium access control among a plurality of nodes (102, 104, 106, 108, 110, 112, 114) wherein the communication system (100) is a wireless communication system (100). The communication system (100) is directed to decentralized control of synchronization among the plural nodes (102, 104, 106, 108, 110, 112, 114). Any node used to control the system may switch from one master node to another master node.



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FREQUENCY HOPPING MEDIUM ACCESS CONTROL PROTOCOL

BACKGROUND OF THE INVENTIONField of the Invention:

5 The present invention relates generally to communication among plural nodes, and more particularly, to control of wireless communication among nodes using frequency hopping radio signals.

State of the Art:

10 Communication systems, such as local area networks (LANs), have achieved widespread use for the exchange of information. These systems include a plurality of data processing nodes, or "agents", which contend for access to a communication medium that interconnects the nodes.

15 Typical communication networks use hardwired interconnections, such as the local area network communication system described in U.S. Patent No. 4,661,902 (Hochsprung et al). More recent efforts have been directed to developing wireless communication
20 networks. For example, commonly assigned U.S. Patent No. 5,231,634 (Giles et al) relates to a communication system for regulating communication among a plurality of nodes, each of which is equipped with a radio transceiver. The '634 patent describes medium access
25 control of a wireless LAN to provide decentralized, peer-to-peer access for all of the agents. A peer-to-peer communication system is one in which all agents can freely communicate without any agent having an advantage over another.

30 Wireless communication systems require consideration of potential problems which do not exist in hardwired systems. For example, in a wireless communication system, the nodes can be mobile, moving

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in and out of range with other nodes in the system. The '634 patent is directed to continuously ensuring that all agents possess fair access to the communication system (i.e., to avoid, for example, agents which are physically closer to a given destination from having an unfair advantage due to their signal strength being greater than that of agents physically located further from the destination).

Due to their unique considerations, wireless communication systems have not been developed which can exploit communication techniques such as frequency hopping. Frequency hopping is a known spread-spectrum technique whereby a signal is transmitted using a plurality of frequencies. The exact frequency used at any given time is switched from one frequency to another either in a random or a predetermined sequence.

Frequency hopping techniques provide reliable and secure wireless communication. However, conventional frequency hopping techniques are not readily adaptable to a wireless LAN environment, such as the LAN described in the '634 patent. For example, in frequency hopping systems, synchronization among transmitting and receiving stations constitutes a significant problem. In a LAN environment, synchronization becomes a more significant problem since nodes can move into and out of any number of dynamically changing, reconfigurable communication systems, each of which can have an independently synchronized frequency hopping sequence. There is presently no mechanism for establishing and maintaining synchronization among the nodes present in a dynamically changing, reconfigurable communication system.

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SUMMARY OF THE INVENTION

Accordingly, the present invention is directed to providing wireless frequency hopping communication among a plurality of nodes. For example, the present invention is directed to features such as (1) synchronizing frequency hopping communication of a dynamically changing, wireless communication system having plural nodes; and (2) automatically resolving which of the plural nodes of the dynamically changing communication system is best suited to control synchronization (e.g., which node can establish synchronized communication among the greatest number of nodes at any given time). Exemplary embodiments provide decentralized control of synchronization whereby a master node used to control synchronization of the communication system can dynamically change as the communication system is dynamically reconfigured.

Generally speaking, exemplary embodiments of the present invention relate to an apparatus and method for controlling frequency hopping communication among plural nodes in a communication system by transmitting a synchronization signal from a first node during a predetermined contention-free synchronization period; and synchronizing frequency hopping of at least a second node to said first node via said synchronization signal.

Embodiments of the present invention also relate to an apparatus and method for controlling frequency hopping communication among plural nodes in a communication system by assigning each of the nodes a hierarchical designation representing a priority of the node to control synchronization of the communication system; initializing the communication system by synchronizing the nodes to a first node; searching the communication system to locate a second node to control synchronization of the communication system; and

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synchronizing the communication system to the second node if located.

BRIEF DESCRIPTION OF THE DRAWINGS

5 The present invention can be further understood with reference to the following description and the appended drawings, wherein like elements are provided with the same reference numerals. In the drawings:

10 Figure 1 illustrates a multiple master-node configuration for an exemplary communication system in accordance with the present invention;

Figure 2 shows a frequency hop period in accordance with an exemplary embodiment of the present invention;

15 Figures 3A-3C illustrate resynchronization of a communication system to a second node in accordance with an exemplary embodiment of the present invention;

Figure 4 illustrates a search for multiple master nodes in a communication system in accordance with an exemplary embodiment of the present invention; and

20 Figures 5-9 show flow diagrams of an exemplary initialization, synchronization and master node resolution operations in accordance with exemplary embodiments of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

25 1. Overview

30 Figure 1 illustrates an exemplary embodiment of a communication system 100 for controlling communication of frequency hopped signals among a plurality of nodes 102-116 (e.g., communication stations). In accordance with the present invention only nodes which are synchronized to one another can communicate with one another. A frequency hopping medium access protocol in accordance with the present invention can be used to control communication among the nodes in server based

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networks, peer-to-peer networks, ad hoc networks and so forth.

Frequency hopping within a communication system is performed by transmitting/receiving information using
5 any number N of different frequencies (e.g., a prime number, such as 79 or 83 different frequencies). The communication system repeatedly switches frequencies during communication, sequencing through all N
10 frequencies of the hop sequence. The frequencies are switched in either a random or a predetermined sequence (i.e., the hop sequence). A random sequence can be used if a mechanism is in place whereby both a transmitting node and a receiving node use the same random generation technique, or if the transmitter
15 communicates the random sequence to the receiver.

The system remains at each of the different frequencies of the hop sequence for a selected period of time, referred to herein as the hop period. In accordance with exemplary embodiments, the hop period
20 can be fixed at any one of a plurality of different time lengths. For example, in an exemplary embodiment the hop period can be selected to be 100 milliseconds (ms), 200 ms or 400 ms. The hop period is selected by the master node which is in control of synchronization
25 of the communication system at a given time. Once the hop period is set by the master node, it will not vary unless the master node changes the hop period or the communication system resynchronizes to a new master node with a different hop period. All nodes which are
30 synchronized to a particular master node recognize the hop period defined by that master node.

In accordance with the present invention, communication among the various nodes of the communication system is achieved by synchronizing these
35 nodes to the same frequency within the hop sequence, and by aligning the hop periods so that all nodes in

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communication with one another switch frequencies together. In accordance with exemplary embodiments, synchronization is maintained continuously, and not only when a node attempts to initiate or receive
5 communications. Thus, data and other information can be transmitted whenever the communication system is open (i.e., contention-free), without having to wait for a synchronization period to elapse.

In accordance with the present invention, a
10 decentralized, or distributed method of synchronization is used whereby any one of multiple nodes can control system synchronization and communication. Accordingly, each of nodes 102-116 in Figure 1 is assigned a
15 hierarchical designation representing a priority of the node to control synchronization of the communication system. The node which controls synchronization at a given time will be referred to hereafter as a "master node". Any remaining nodes which are in communication range of the master node can be synchronized to the
20 master node. For example, node 102 of Figure 1 can be considered a master node for controlling synchronization of the communication system. However, if node 102 is disconnected (e.g., a mobile communication station which leaves the building), the
25 remaining nodes resolve which node will become the new master node.

In accordance with exemplary embodiments of the present invention, each node is assigned a hierarchical designation representing a priority of the node in
30 contending to become a master node. In an exemplary embodiment, the hierarchical designations are of three different types: (1) a designation of highest priority referred to herein as master station priority; (2) an intermediate priority designation referred to herein as
35 an alternate master station priority which is of a priority lower than that of a master station priority;

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and (3) a lowest priority designation representing nodes which can never control synchronization.

In the above example, the "master node" can be a node of either master station priority or a node of alternate master station priority. Nodes of priority (3) cannot communicate within a communication system unless a master node is located within their range of communication to control synchronization. The nodes of the communication system resolve which node will be the master node for controlling synchronization within the system at any given time.

As referenced herein, the phrase "communication system" refers to one or more nodes which can communicate with each other. Because the nodes are mobile, one or more dynamically reconfigured subsystems may exist within the communication system. For example, a first plurality of nodes may be within communication range of one another and controlled by a first master node. A second plurality of nodes within the communication system may be in communication with one another and controlled by a second master node. Depending on the priority assigned to each node, it is possible that a single node which can communicate with some of the first plurality of nodes and with some of the second plurality of nodes will attempt to become a master node. Whether the single node will be successful or not depends on master node resolution.

In the following discussion, a general manner by which the nodes communicate using a frequency hopping technique will be presented. This discussion will be broken into two general topics: (1) a format by which the nodes communicate (e.g., initialize and synchronize) using frequency hopping; and (2) a manner by which the node best suited to be the master node for controlling synchronization is resolved.

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2. Communication Format

a. Hop Period

Figure 2 illustrates a time oriented relationship of an exemplary hop period 200 with the total time duration selected for the hop period being indicated in a synchronization message 204 (i.e., Sync MSG) from the master node. The phrase "hop period" can be abbreviated to "hop".

A master node controls synchronization of nodes in the communication system by transmitting the sync message. A beacon period is included in the hop period as an aid to facilitate synchronization. The beacon period permits faster synchronization of a node to a master node. A node receiving the beacon can lock onto the frequency of the beaconing master node prior to receipt of a sync message. Each of the sections set forth in the exemplary Figure 2 hop will now be described.

(1) Beacon Period - The beacon period ensures that there is energy present at the current frequency (i.e., a beacon frequency) long enough for any receiver node to scan all possible frequencies in the hopping sequence. In addition, information is included in the beacon to allow a receiver, once it has detected energy in a particular frequency, to determine whether this beacon has the appropriate channel/subchannel information. To detect a beacon, nodes continuously sequence through all N frequencies of the frequency hopping sequence looking for a beacon transmitted by a master node. The master node sends the beacon for a long enough period of time to enable a node to scan all N frequencies during a scanning period. The length of time the master node sends the beacon to ensure that other nodes will have an opportunity to scan all N frequencies is the beacon period 202.

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The beacon period 202 is a fixed duration, contention-free period of time during which a beacon message is broadcast by the master node. This feature ensures that a node of master station priority can immediately transmit information for establishing communication with other nodes of the communication system, without first monitoring the communication medium before transmitting such information. This avoids delays typically required for a node to transmit such information in, for example, a server-based communication system. The master node can be configured to beacon, for example, every 1 to 8 hops for the purpose of optimizing sync times versus overhead for a given installation.

One example of a beacon is a signal which includes the following sequence: a first delay period (i.e., Delay 1); a Preamble; a second delay period (i.e., Delay 2); and a beacon message. The four components of this sequence can be repeated any number of times, end-to-end, for an entire length of beacon period 202. Each of these four components can be described as follows:

25	Delay 1	This delay is the time it takes to change from switching to send a Beacon Message to the time it takes to send a Preamble message.
30	Preamble	The inclusion of a Preamble makes it easier for nodes to lock onto a particular master node (e.g., a waveform constructed to provide easy lock, which is appended to the start of a data packet).
35	Delay 2	This is the time it takes to transition from sending a Preamble to sending a Beacon Message.
40	Beacon Msg.	A beacon message corresponds to a short data packet for telling other nodes (a) a channel at which the master node is operating; (b) a subchannel on which the master node is operating; and (c) at

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5 which frequency the master node is
operating (i.e., which of the N
frequencies). The beacon message is
optimized for efficient searching by the
remaining nodes. The Beacon Message can
include, for example, 5 data bytes, 2
flag bytes, and 2 cyclic redundancy
check (CRC) or checksum, bytes. Flag
bytes represent framing bytes in between
10 which data can be transmitted.

The foregoing beacon sequence is by way of example
only, and those skilled in the art will appreciate that
any signal or sequence of signals can be used as the
beacon. For example, the above beacon could be
15 modified to exclude the preamble and/or the delays.
The beacon could merely be an energy bearing signal for
indicating to receivers that a sync message will
follow.

An appropriate beacon period should be selected to
20 account for any time a receiving node requires to
prepare for reception of each frequency of the
frequency hopping sequence (i.e., the radio period, or
key-up time) and the time the receiver must listen at a
frequency of the frequency hopping sequence to detect
25 the beacon message (i.e., beacon listening time).

The radio key-up time can, in an exemplary
embodiment, include the time required to receive a
preamble within a beacon period. A worst case
situation occurs when the preamble has just been missed
30 by a receiving node such that the node must wait for a
subsequent preamble to be sent. Thus, a minimum radio
key-up time should correspond to a sum of two
preambles, delay 2, a beacon message and delay 1.

A beacon listening time corresponds to an amount
35 of time required for a node to listen at the frequency
at which the preamble was detected during a scan
through all N frequencies. The beacon listening time
must be long enough to guarantee that a beacon message
sent at that frequency will be detected. A worst case

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occurs when a node fails to detect a beacon message such that a receiver of the node must wait for a subsequent beacon message. Therefore, in an exemplary embodiment, a beacon listening time corresponds to a sum of two beacon messages, delay 1, delay 2 and 1 preamble.

A beacon period can be calculated as the number N of available frequencies in the frequency hopping sequence multiplied by the radio period, plus the beacon listening time. Thus, a beacon period represents the time required to switch through each of the N frequencies, prepare the radio, and listen at the beacon frequency long enough to detect a beacon message.

In summary, the beacon message broadcast during the contention-free beacon period permits other nodes within the communication system to determine that they have identified a correct frequency of the hopping sequence, as well as the channel and sub-channel with which the master node is broadcasting. However, the nodes controlled by the master node also need to determine when to switch frequencies (i.e., synchronize their hop periods), since frequency switching must occur for all stations in the communication system at the same time. Synchronization information for synchronizing to a hop period of the master node is not included in the beacon message. Rather, information pertinent to synchronizing is included in a sync message (i.e., Sync MSG).

(2) Sync MSG - Sync message 204 enhances the ability of a node to quickly synchronize to a communication system. Although a beacon period is only included in hop periods which have been designated to include a beacon (e.g., once every 8 hops), the sync message is included at the beginning of every hop period, regardless of whether a beacon message is

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broadcast within the hop period. A master node may only broadcast its contention-free beacon once every x (e.g., 8) hop periods to minimize its contention-free control of the communication medium. However, Sync message 204 contains pertinent information to allow nodes to sync to the master node, and this information can be broadcast on every hop so that nodes can update their hop interval times and adjust for drift. The sync message can also contain pertinent information concerning a contention-free outbound period during which a master node can broadcast information to all nodes of the communication system without contention.

When a beacon message has been located, nodes can identify which channel and frequency (i.e., hop number) the master node is currently on to aid in the synchronization process. The sync message is used to transmit a hop timer count which reflects a count remaining on a hop timer of the master node when it sets up the sync message. The hop timer tracks the time duration of a hop period. Based on the remaining count transmitted by the master node in the sync message, a node can subtract the appropriate count for processing and transmission delays, and then write the remainder into a hop timer register so that its hop timer interrupt will occur at approximately the same time that a hop timer interrupt occurs in the master node. This allows the node to synchronize its hop period to the hop period of the master node.

(3) OutBound - A master node can communicate messages to all nodes with which it is synchronized in a communication system during a contention-free outbound period 206. The outbound period 206 can be used by master nodes to off load any queued data without contention. This allows optimum transfer of data for the master node, and can be used for configurations where the master node is, for example,

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also the server in a LAN. The outbound period is of variable length as required. For example, this period can be expanded in hops which do not include a beacon period. A master node can be configured to transmit a maximum number of messages that can be transferred during this period, or any number of messages less than the maximum, with the minimum equal to 0.

(4) Time Bounded - An optional, contention-free, time bounded period 208 can support time bounded services.

The period of time represented by the beacon period, the sync message period, the outbound period and the optional time bounded period collectively represents a first period of time, referred to herein as a contention-free "A" period. The remaining portion of the hop period is a contention period during which nodes synchronized to one another within a communication system vie for access to the communication medium. This contention period is referred to herein as a "B" period which is initiated by what is referred to herein as a "start of B". During the contention period, nodes can contend for access to the communication medium using a contention protocol such as that described in commonly assigned U.S. Patent No, 5,231,634, the disclosure of which is hereby incorporated by reference in its entirety.

(5) Start of B - A start of B message 210 is broadcast by the master node to announce the start of a "B period" to all nodes.

(6) B Period - A "B" Period 212 is a random access contention period during which the master node and all other nodes can communicate with one another.

Having discussed the contents of a hop period used by nodes to communicate in accordance with exemplary embodiments of the present invention, attention will now be directed to the scanning period. A scanning

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period corresponds to a period during which a node scans for a beacon to synchronize to a master node. A scanning period is also used to search for beacons to detect the existence of other nodes (i.e., of master station priority or alternate master station priority) transmitting beacons.

b. Scanning Period

A scanning period corresponds to the time a non-master node searches before determining that a master node does not exist. For example, when a master node sends a beacon at least once every 8 hops, nodes must locate a beacon within that period. In a normal hopping sequence, a transition from one frequency to a next frequency occurs in a predetermined non-sequential order in accordance with exemplary embodiments. However, when a node is searching for a beacon, it will begin scanning with the current frequency it is on and go up in frequency in sequential order until the Nth frequency is scanned. The hopping sequence then wraps around to the first frequency and continues through the sequence of frequencies again.

c. Frequency Drifting

Hop timers included in the nodes are resynchronized every hop period to correct for errors associated with tolerances of the timing references for each node. Each hop period, synchronized counters may be off by several counts, and if nodes are not resynchronized often, they can drift. Because the nodes are resynchronized every hop period, frequency drifting is corrected in each hop period.

However, exemplary embodiments can also account for frequency drift at the beginning of each hop period. For example, the master node can delay sending the sync message for a predetermined period of time

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referred to herein as a drift period. The master node need not delay sending the beacon during hops which include a beacon period because it is not important for synchronized nodes to receive beacon messages. With
5 the exception of the beacon, no data is sent at the beginning or end of a hop period within the drift period.

The drift period differs depending on the hop period length. In exemplary embodiments, sync messages
10 can be missed for a maximum of 4 hop periods before a determination is made that synchronization has been lost. In this case, the error rate must be multiplied by 4. The result is multiplied by 2 to account for the master node being off by a gain of 100 parts per
15 million (PPM) while the node is off by a loss of 100 PPMs, creating an error rate of approximately .08%.

d. Message Format

To provide communication between nodes using frequency hopping and synchronization, a protocol for
20 transmitting data and other information can be established in accordance with the aforementioned U.S. Patent No. 5,231,634. In accordance with exemplary embodiments, data can be transmitted in frames, with different frame types being employed as necessary.
25 Each frame can include a frame header, and additional remaining unused bits which are reserved and set to zero unless otherwise specified.

In accordance with exemplary embodiments, a standard frame header can be used on all frames with
30 the exception of a beacon message. A standard frame header includes a flag to indicate the start of the frame, an identification code of a transmitting node (e.g., whether the node is a master station, alternate master station, or a low priority station) control
35 information, (e.g., transmission power level, data

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compression technique, radio speed, and so forth), medium access control length (e.g., frame length from node/frame up to CRC), security information, and channel/subchannel. The node/frame type portion of the standard header can specify antenna diversity (i.e., indicating which antenna is to be used as the sending node), the node type (i.e., master station, alternate station or station) and the frame type. Different types of frames include a beacon frame, a resync frame, a resync acknowledgement frame, a sync frame, a request-to-send frame (RTS), a clear-to-send frame (CTS), a request media access frame (RMA), a medium access control acknowledgement frame (MACK), a logical link control acknowledgement frame (LACK), a data message frame, a wake-up message frame, and so forth.

Source and destination addresses for information included in the frame can be included in an extended header definition specified by the user. The standard frame header can include a header followed by a destination address and a source address.

A start of B message can be sent by a current master node to indicate the start of a contention period. Nodes must hear the message to participate in the contention period, and nodes, upon receiving this message, will use a slot definition and apply it to the current hop. The start of B message contains a field which defines the maximum time to wait for successive start of B messages on successive hops before starting contention without it.

A beacon message can be energy (e.g., a message) which is sent at the beginning of some hops by the master node. In an exemplary embodiment, the beacon message can be a relatively short message that is repeated several times. A beacon message can include a flag to indicate the start of the beacon message, a frame type indicator to confirm that a beacon message

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is being transmitted, a security identification of the master node sending the beacon message, the channel and subchannel of the master, a CRC portion and an ending flag.

5 A resync message can, in accordance with exemplary
embodiments, have one of two versions. A first version
is a broadcast message sent by a master in an outbound
period to inform all nodes synchronized to the master
node that a second master node has been located to
10 which all other nodes should synchronize. This first
version of the resync message requires no
acknowledgement. A second version of the resync
message can be a directed message from a node
designated as an alternate master to a first master
15 station node during the contention period to inform the
first master station that a second master station node
exists. The alternate master node sends information
about the second master to the first master station
node. Upon receipt of this information, the first
20 master station sends a resync acknowledgement message
to inform all nodes of the identity of the new master
(i.e., the identity of either the first master node or
the second master node, depending on a master
resolution protocol). This message includes the medium
25 access control extended information, the
channel/subchannel of the new master, the hop number
which serves as an index into the channel frequency
table to find a sync message, a hop duration, CRC
information and an ending flag. A resync
30 acknowledgement message is sent from a master node and
broadcast to all stations. This acknowledgement
message can be sent in response to a node sending a
resync message to the master node, and it informs all
nodes synchronized to the master node to resynchronize
35 to a new master at the frequency specified in the
message. Thus, a resync acknowledgement message

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includes an extended medium access control, a channel/subchannel of the new master, a sync hop number used to locate the sync message, a hop duration, a new master identification to which all communications should synchronize, a CRC portion and an ending flag.

The Sync message sent by a master node at the beginning of each hop period contains information for nodes to adjust their hop timer counters to maintain synchronization from hop to hop. A synchronization message includes an extended medium access control portion, a node name (e.g., ASCII) of the master node, a control portion for defining the hop (i.e., whether next hop will/will not contain beacon, whether hop is dedicated to searching, or whether regular hop), a hop number, a hop duration, a CRC portion and an ending flag.

3. Master Resolution Protocol

a. Initialization

In accordance with the present invention, exemplary embodiments include a step of initializing the communication system by synchronizing the nodes to a first node. Initialization of a node designated with a master station priority is relatively straightforward. When a node designated with a master station priority is requested to initialize, it immediately sets its hop timer and starts beaconing and sending sync messages. Because it is of the highest priority, it does not search for other nodes of master station priority before attempting to assume a role as a master node itself. Non-master nodes (e.g., a low priority node or a node of alternate master station priority which is not currently operating as a master node) initialize by first scanning for a beacon during a scanning period. Depending on a configuration of the communication system, a node will scan for a beacon

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which matches a subset of its channel and subchannel (as well as any security identification information).

Figure 5 illustrates an exemplary flow chart depicting operation associated with initialization of a non-master node. As illustrated in Figure 5, a non-master node, when asked to initialize, initiates a scan period wherein the non-master node begins scanning for a beacon by keying-up its receiver to sequentially receive each frequency of the hopping sequence. As illustrated by blocks 510 and 514, the receiver is first keyed-up to receive one of the frequencies of a hopping sequence (i.e., the current frequency at which it is set up for). If a carrier is not detected, operation returns from decision block 516 to decision block 510 wherein the next frequency in the frequency hopping sequence is selected.

In an exemplary embodiment, the scanning can continue by sequencing through each frequency up to the frequency in the hopping sequence. The sequence of repeatedly setting up to receive one of the frequencies in the hopping sequence continues until either a carrier is detected in block 516, or all frequencies of the hopping sequence have been scanned. In the latter case, operation exits block 512 to increment a cycle counter in block 518.

Referring to the decision block 516 of Figure 5, if the node detects a carrier from a master node during the scanning period, the node then attempts to synchronize to that master node. This is reflected by initiation of a beacon listening time in block 526 wherein the node listens for a beacon message to detect channel and subchannel information of the master node. If no beacon is identified within the listening time, then the flow chart returns to the scanning mode represented by block 510. Alternately, if a beacon is identified in block 526, then the node will synchronize to the master node upon detection of a sync message in

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block 528. If no sync message is received within a timeout period, the node again rescans via block 510. Alternately, if the sync message is received, the node synchronizes to the master node which had transmitted the beacon and sync message, whereby synchronization is established in block 530.

In accordance with exemplary embodiments described herein, a node should be synchronized within a maximum time period corresponding to the scanning period; i.e., within a number of hops (e.g., x hops) when the master sends a beacon once every x hops. Any number of scanning cycles can be included in a scanning period to locate a signal transmitter from another node. A cycle count timeout can be the scan period divided by the product of N times the radio-key-up time, as represented by block 520. A rescanning via blocks 510-516 will be performed until such timeout occurs.

Once a timeout occurs in block 520, the node determines that it was not able to initialize by synchronizing to another master node in the allowable time period. If the node is of the lowest priority, it can attempt to rescan as represented by the "no" decision path from block 520. Alternately, the node can discontinue scanning and report that a master node could not be located. If the node is of an alternate master station priority, it can attempt to assume control of the communication system by becoming a master node as represented by decision block 522. In this case, the node initiates a master node initialization as represented by block 524.

As illustrated in Figure 6, a master node initializes by attempting to control (i.e., establish) synchronization within the communication system. Nodes of alternate master station priority also will perform the master node synchronization control steps illustrated in the flow chart of Figure 6 upon failure

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to synchronize to a master node in accordance with the Figure 5 flow chart.

As described previously, a node of master station priority initializes by keying up to send its beacon in its first available beacon period. On the other hand, a node of alternate master station priority only keys up to send a beacon after a search for other beacons during a scanning period is determined to have been unsuccessful.

According to Figure 6, the first step of synchronization control during initialization by a master node is represented by block 610 wherein the master node waits for a hop timer interrupt. The hop timer interrupt is generated when the hop timer expires, and is used to trigger a decrement of the number of hops prior to entering a beacon period, as reflected in block 612. When the node is of an alternate master station priority, it also decrements a count representing the number of hops prior to searching for another master node, as represented by block 614.

If the value of the number of hops to search reaches zero as represented by the decision block 616, the number of hops to search is reset in block 618 and the alternate master station node searches for other master nodes.

To perform a search for other master nodes, a master node sends a beacon period 620 followed by a sync message 622 which has two significant attributes. This sync message sent by a master node notifies all nodes of the communication system that the current hop has been dedicated for searching. In addition, the sync message sent by the master node includes a hop timer count adjusted to scan an entire hop period. If the count is not adjusted, a search time 624 will not correspond to a full hop period, such that another master node beacon message could possibly be missed.

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Figure 3C illustrates a search hop period 306 which is longer than other hop periods by an amount corresponding to the beacon period plus the sync message.

5 As illustrated in Figure 9, if another master node is not located during a search for multiple master nodes, the hop timer interrupt brings the master node out of the scan phase and the master node continues with its normal hopping sequence (block 626).

10 However, if the master node locates a beacon message during its scan, it sets a resync flag in block 628 and awaits the sync message from the other master node and then prepares a resync message. After
15 extracting information from the sync message, the first master node waits for its hop timer interrupt in block 610 and then sequences to its next operating frequency. It proceeds normally, sending a beacon if necessary and a sync message. However, in the outbound portion of the hop period it sends a resync message (block 642).
20 The destination address of this message is set so that it is broadcast to all nodes. The resync message contains information which allows nodes to synchronize to a new master quickly. Further, the resync message informs all nodes to synchronize to a new master when
25 the current hop period ends.

 More particularly, where the node is either an alternate master station which has assumed the role of a master node or is a node of master station priority, operation flows to decision block 630 once the number
30 of hops to beacon has been decremented to zero. The number of hops to beacon is then reset in block 632 and a beacon is sent in block 634. On the contrary, if the number of hops to beacon was not set to zero in block 630, indicating that the current hop period does not
35 include a beacon period, then a delay drift period is performed in block 636.

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After the delay drift period of block 636 or the sending of a beacon in block 634, a sync message is sent in block 638. In block 640, a determination is made as to whether the resync flag was set in block 628. If the resync flag was set in block 628 (i.e., another master node was located), then a resync message is broadcast in block 642 to inform all nodes that another master node exists to which all nodes should synchronize. This resync message is based on the detection of another master in block 624, and requires no resync acknowledgment. Alternately, if the resync flag was not set or if a resync message from block 642 is to be sent, an outbound period is entered in block 644, followed by a start of B message in block 646 and a contention period in 648. Because Figure 6 relates to master nodes, the resync message of block 642 can be sent in a contention-free outbound period.

During the contention period, the node can send a resync acknowledgement in block 650 to confirm the identity of a new master node. During a subsequent hop period, the node will resync to the new master node. More particularly, upon expiration of the hop timer, a decision is made in block 652 whether the resync flag had been set. If the resync flag has not been set, operation returns to block 612 to initiate the next hop period via the switch frequency block 626. Alternately, if the resync flag has been sent, then a resync operation occurs as represented by block 654.

Figure 7 illustrates a synchronization operation for a non-master node. As represented by blocks 710 and 712, the non-master node switches frequencies within the hop sequence upon each hop timer interrupt. Further, the non-master node decrements the number of hops to beacon and decrements the number of hops to search in blocks 714 and block 716. Because the node is a non-master, if the number of hops to beacon is

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zero, as represented by the decision block 718, the beacon period is skipped in block 720.

The node subsequently enters a listening period in block 722 to receive messages from the master node during the contention-free sync message and outbound periods of the master. When a synchronization message is received, the node extracts and sets a number of hops to beacon and a number of hops to search from the master node in block 724. These values are then used to set similar values within the non-master node.

If the number of hops to search is zero, and the node is of an alternate master station priority, as represented by blocks 726 and 728, then a search for a master node is performed during a scanning period in block 730. If a master is found, a resync flag is set in block 732 and operation returns to block 710. The resynchronization process starts in the next hop period. If a master is not located in block 730 (i.e., the hop timer expires), operation returns to block 712 to switch to the next frequency and initiate a new hop period.

If the node is not of alternate master station priority, as represented by the "no" decision path from block 728, operation returns to block 710 to initiate the next hop period without searching for other master nodes. Rather, the node is of the lowest priority, and will resynchronize to a new master upon receipt of a resync message. If a resync message is received (i.e., a message instructing the node to synchronize to a new master node), then the resync flag is set in block 734 and operation returns to listening block 722. Further, if the number of hops to search was not decremented to zero in the decision block 726, operation returns to the listening period 722.

During the listen period 722, the start of B period can timeout or the start of B can be received. If the start of B period times out and the number of

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hops to search is zero, or the start of B period has been indicated and such indication has been received during the listening period 722, then a decision block 736 is used to determine whether a resync flag has been set. If the resync flag was set in response to receipt of a resync message identifying existence of another master in block 734, a resync message identifying to the current master that the other master exists is placed into a priority queue as represented in block 738. Alternately, if the resync flag was not set in block 736, then a contention period is entered in block 740. If a resync acknowledge message identifying a new master node has been received from another node during the contention period, then the resync flag is set in block 742 during the contention period 740.

Once the contention period ends (i.e., the hop timer expires), the determination is made in block 744 as to whether the resync flag has been set in block 742 and if so, a resync operation is performed as represented by block 746. Alternately, operation returns via the "no" path from block 744 to initiate a subsequent hop period via the switch frequency block 712.

The initialization sequence for a node assigned a priority designation of an alternate station is randomized in an exemplary embodiment. In the event all nodes are initialized at the same time, alternate stations can scan an extra amount of time in addition to the regular scanning period discussed previously. For example, a value corresponding to the least significant 6 bits of a node's identification code can be multiplied by 25 ms. The result is the extra scanning time of an alternate master station, and the maximum initialization time for nodes designated alternate master stations thus becomes 4.78 seconds (i.e., 63 multiplied by 25 ms plus 3.2 seconds). Although this calculation does not guarantee that only

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one master node will exist, it represents an effort to reduce the number of multiple masters so that selection of a single master node can be resolved more efficiently.

5 When synchronization of any of the foregoing nodes to the communication system is lost, or when a node is instructed to synchronize to a new master, an effort is made to resynchronize. More particularly, all nodes receive the sync message from the master node on each
10 hop and reset their timers upon receipt of the sync message. If a node does not receive a sync message for a set number (e.g., 4) of consecutive hops, synchronization with a master node is considered lost. To resynchronize, the node which has lost
15 synchronization scans for a master node beacon. If a master node is not located within the scanning period, the node which has lost synchronization performs an initialization procedure as described previously.

 Figure 8 illustrates an exemplary operation of a
20 resynchronization operation. As represented by block 810, a resync operation is initiated in a subsequent hop period as represented by waiting for a hop timer interrupt. Once received, the node is keyed-up to the resync frequency in block 810 and a timeout is set
25 (e.g., 800 milliseconds as illustrated in block 814). Afterward, the node waits for receipt of the sync message in block 816. Once received, the non master node can be considered synchronized as represented by block 818. Alternately, if a timer expires, the node
30 reinitializes as represented by block 820, thereby assuming that it has lost any ability to resynchronize.

b. Searching for Multiple Master Stations
 (Master Stations)

35 As described above, exemplary embodiments of the present invention scan the communication system to search for and locate a second node to control

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synchronization of the communication system (i.e., scan the communication system in search of multiple master nodes). To synchronize all nodes of a communication system, nodes of alternate master station priority (i.e., either acting master nodes or not) will occasionally search the communication system to determine whether another master node exists within the system. To ensure that another master node can be located, the scan period is set to cover an entire beacon period. To avoid eliminating communication transfers for a significant amount of time, a prime number Y can be chosen such that every Y hops, the master node will search for a beacon message. If the other master node beacons every X hop periods, the present master node should locate the other master node within X multiplied by Y hop periods.

Figure 9 illustrates an exemplary flow chart depicting operation of a master node resolution operation. In block 910 of Figure 9, a given node will search for other masters. If another master is found, a resync message is prepared in block 912 to inform a current master node of the existence of another master node. The interrupt is received upon expiration of the hop timer.

If the node is of master station priority (see block 916), it sends a resync message during its contention-free outbound period as represented by block 918. Alternately, if the node is not of master station priority (e.g., of alternate master station priority), the node waits for a contention period as represented by block 920.

Upon receipt of the start of B message, the node determines whether a resync message has been received in block 922. If so, the node initiates a resync operation as described previously and as represented by block 924. Alternately, if a resync message had not been received in the decision block 922, the node sends

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a resync message in an effort to inform the master mode of another detected master node (see block 926). The node then waits for a resync acknowledgement in block 928 identifying which node will be the new master.

5 If a resync acknowledgement was not received in block 928, the node continues operation as usual, remaining synchronized to the master node with which it was originally synchronized (see block 930). Alternately, if a resync acknowledgement was received,
10 this verifies to the node that it should resynchronize to a new master or assume a role as a master node (see block 932). Upon receipt of a resync acknowledgement, the node determines whether the resync acknowledgement was indeed intended for it to assume control, as
15 represented by decision block 934. If not, the node performs a resync operation to the current master node as represented by block 924.

 If the resync acknowledgement was received, the node addressed in the message resynchronizes to a new
20 master identified in the resync acknowledgement as represented by block 936. A resync message is sent during the contention period (i.e., the B period) of the new master node as represented by block 938. Afterward, the node waits for a resync acknowledgement
25 in block 940. If it is to become a master node, it performs a master node initialization operation in block 942.

 There is a possibility that when a first master node scans, a second master node will also be scanning,
30 whereby the two master nodes scan together and never locate each other. To minimize a possibility of this occurrence, master nodes can, in an exemplary embodiment, always send beacon messages before scanning to allow master nodes which are at least a beacon
35 period plus a sync message apart in their hop synchronization to detect each other. This is illustrated by the transmission characteristic 300

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illustrated in Figure 3A for each of a first master node (i.e., labelled master station 1) and a second master node (i.e., labelled master station 2).

During a power up sequence where all nodes are
5 initialized concurrently, it is also possible that master nodes could be synchronized so closely as to create a problem in identifying each other. To resolve this occurrence, some randomness can be added when a node is delaying to become a master node. Further,
10 when a node of alternate master station priority scans, it can begin scanning on its own frequency first to allow master nodes to detect each other if they are unsynchronized by more than a beacon listening time plus a sync message time (e.g., a few hundred
15 milliseconds). As illustrated in Figure 3B, if the two master nodes are offset in synchronization by a relatively small amount, a small window 302 of the beacon will fall into the search time 304. If the master node searches its own frequency first, it should
20 find another master node which is in close synchronization with itself. As illustrated in Figure 9, if another master node is not located during a search for multiple master nodes, the hop timer interrupt brings the master node out of the scan phase
25 and the master node continues with its normal hopping sequence (block 930 in Figure 9). However, if the master node locates a beacon message during its scan, it awaits the sync message from the other master node and then prepares a resync message (block 912). After
30 extracting information from the sync message, the first master node waits for its hop timer interrupt (block 914) and then sequences to its next operating frequency. It proceeds normally, sending a beacon if necessary and a sync message. However, in the outbound
35 portion of the hop period it sends a resync message (block 918). The destination address of this message is set so that it is broadcast to all nodes. The

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resync message contains information which allows nodes to synchronize to a new master quickly. Further, the resync message informs all nodes to synchronize to a new master when the current hop period ends.

5 c. Searching For Multiple Nodes (Alternate Stations)

At the beginning of every hop period, the current master node sends out a sync message which nodes use to readjust their timers to remain synchronized (see block 638 in Figure 6). To perform a search for other master nodes in accordance with block 910 of Figure 9, a sync message is sent in block 622 of Figure 6 which includes a control field that can be set to inform the other nodes that the entire hop period is a master node search phase dedicated to search for another master node; i.e., there will not be an outbound period or contention period B in the current hop. Nodes which are not configured as alternate stations remain idle, but nodes configured as alternate master stations, along with the current master node, scan for another master node. Nodes designated as alternate master stations search to detect a master node that is out of range with its master node. In this case, the alternate station becomes the master node. Thus, any alternate master station must be capable of reporting back to its own master node, synchronizing to a new master node, and taking over as master node.

An alternate master station scans for a beacon in the master node search phase represented by block 624 of Figure 6 and block 910 of Figure 9. If no beacon messages are found, it returns to its normal procedures when it receives its hop timer interrupt (block 930). If the alternate finds a beacon message during its scan, it waits for the sync message of the newly found master and then prepares a resync message to identify the second master node which is located to the current

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master node (block 912). After extracting information from the sync message, it waits for its hop timer interrupt (block 914) and communicates the resync message back to its original master node.

5 If the node is itself a master node which detected another master during the scan hop, it will send a resync message in the outbound period block 642 in Figure 6 and block 918 in Figure 9). However, if the node is of alternate master priority, it must wait for
10 the contention period (block 920). If the node receives a resync message from the master node, it proceeds normally until it receives its hop timer interrupt, at which point it attempts to synchronize to a new master (block 924). Alternately, if a resync
15 acknowledgement message identifying a new master node is not received, the alternate master station will retry sending the resync message to the master node in the contention period (block 926).

 If a resync acknowledgement message is received
20 (block 928), but another alternate master station's identification code is given as the new master, the alternate master station will not become a master and will resynchronize at the end of the hop period (i.e., return to block 924). If the alternate master station
25 receives the resync acknowledgement message with its own identification code given as the new master, it waits for its hop timer interrupt and synchronizes to the new master (block 936). Once synchronized, it waits for the contention period B where it sends a
30 resync message to the newly synchronized master node (block 938). If the alternate master receives an acknowledgement for another identification code to become master, it will resynchronize. However, if it
35 receives a resync acknowledgement for it to become a master node (block 940), it waits for the hop to end and takes over as master. It beacons on this hop to

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synchronize other scanning stations as soon as possible (block 942).

d. Synchronizing to a New Master (Resync)

The simplest way for nodes to synchronize to a new master is to search for the beacon. However, this would make communication between these nodes impossible until they find and synchronize to the new master. If maximum sync times are chosen to be very fast (hop periods are short or beacons are sent frequently), this method would be acceptable. However, if the maximum hop period (400 ms) is used and beacons are sent minimally (once every 8 hops), communication would be held off for 3.2 seconds.

In accordance with alternate exemplary embodiments, nodes can synchronize to a new master (Figure 8) by informing the nodes which hop number the new master will be at so they can scan for the sync message at that frequency. To calculate the hop number, the master node includes a few bits in the sync message of block 816 to indicate the hop period it is using (100, 200, or 400 ms), as well as the current hop number. As illustrated in Figure 4, if the hop period of the current master node is X and the hop period of the new master node is Y, the maximum number of hops the new master can make is the number it can make in 2 X hop periods. That is, the worst case occurs when the scanning node detects the beacon message at the beginning of its search period. The scanning node has to wait for its hop period to expire and transmit a resync message to the other nodes on the next hop. The nodes resynchronize after this hop period.

The new master node can move at most $((2 \times X) / Y)$ hops from its current hop. This number is added to the new master's current hop number and sent in the resync message. Nodes receiving the resync message switch to the correct frequency and search for the new master's

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sync message when their hop expires. The worst case occurs when a node finds a new master near the end of the search period. In this case, although $2 \times X$ hops were calculated in, the other master can only move X/Y hops. Therefore, in the worst case, a node waits $1 \times X$ hop period before finding the sync message of the new master. This is a large improvement since nodes are only out of communication for a single hop period at the most (a maximum of 400 ms).

For completeness, it should be noted that a node may not receive a resync message that a master broadcasts, or may not find the sync message of a new master while trying to resynchronize. In the first case, (if a node does not receive a transmitted resync message) the node will wait for a sync message on the following hop, but will never receive one because the master node is synchronized to another master node. After missing four sync messages, the node will reinitialize itself by scanning for a beacon. In the second case, a node expects to find the sync message of a new master within 1 hop period. If the node does not find the sync message within that time, it will also reinitialize itself by scanning for a beacon.

Referring to Figure 1, exemplary operation of a communication system in accordance with the present invention will be described. The communication system 100 of Figure 1 can be considered to include a first subsystem (e.g., network) represented as a first set of nodes 102, 104, 106 and 108, of which nodes 102, 104 and 108 represent alternate master stations. For purposes of the following discussion, node 102 will be considered to represent the acting master node for nodes 102-108. Communication system 100 also includes a second subsystem represented as a second set of nodes labelled 110, 112 and 114, of which node 110 can be considered a node of master station priority. In accordance with the foregoing discussion, alternate

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master station 102 transmits a resynchronization message to nodes 104 through 108, in an effort to have nodes 104 through 108 synchronize to acting master station 110, thereby resulting in synchronization of all nodes to true master node 110. In this case, node 102 of alternate master station priority would lose its status as an acting master. That is, the communication system would dynamically reconfigure to optimize communication among the greatest number of nodes within communication range of one another.

In an alternate scenario, where both the node 102 and the node 110 represent alternate master stations, node 102 will again transmit a resynchronization message. If the node 102 locates the node 110, the node 102 will transmit a resynchronization message to nodes 104 through 108 during a contention period in an effort to have nodes 104 through 108 synchronize to node 110.

In accordance with another example, assume that node 102 is of alternate station priority (as opposed to master station priority) and that node 102 has acquired status as an acting master node for all of nodes 102-114. If node 102 subsequently detects the existence of alternate master station 116 during a searching period, node 102 sends a resync message to nodes 104-114 in an effort to have nodes 104-114 resync to node 116. Subsequently, all of nodes 104-114 will attempt to resynchronize to node 116. However, if only node 102 is able to resynchronize to node 116, then the remaining nodes 104-114 will select an acting master node from among them and two networks will be established; i.e., a network including nodes 102 and 116, and a second network including the remaining nodes 104-114 of Figure 1.

If during a subsequent beacon period of the master node 110, the node 102 detects node 110, then node 102 will take over as acting master node. In this case,

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node 116 will join node 102 along with nodes 104-114 such that the communication system will have been dynamically reconfigured to optimize the number of nodes in communication with one another. Any time one or more nodes leaves communication range with an acting master node, the system dynamically reconfigures into plural subsystems with separate acting masters.

Of course, numerous scenarios can exist regarding the entry into and departure from a communication system of any number of nodes of varying hierarchal designations. The foregoing examples were merely presented to illustrate exemplary operations of a communication system in accordance with exemplary embodiments of the present invention.

It will be appreciated by those skilled in the art that the present invention can be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The presently disclosed embodiments are therefore considered in all respects to be illustrative and not restricted. The scope of the invention is indicated by the appended claims rather than the foregoing description and all changes that come within the meaning and range and equivalence thereof are intended to be embraced therein.

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WHAT IS CLAIMED IS:

1. Method for controlling communication of frequency hopped radio signals among a plurality of nodes in a communication system, comprising the steps of:
 - 5 assigning each of said nodes a hierarchical designation representing a priority of the node to control synchronization of the communication system;
 - 10 initializing the communication system by synchronizing the nodes to a first node;
 - searching the communication system to locate a second node to control synchronization of the communication system; and
 - 15 synchronizing the communication system to said second node if located.
2. Method according to claim 1, further including the steps of:
 - 20 assigning each of said nodes one of at least first, second and third hierarchical designations, with said first hierarchical designation being of highest priority and with said third hierarchical designation being of lowest priority.
3. Method according to claim 2, wherein said first node is assigned said first priority (MSTA), said step of initializing further including the steps of:
 - 25 sending a synchronization signal from said first node without searching for other nodes of said first priority within said communication system.
4. Method according to claim 2, wherein said first node is assigned said second priority (ALTSTA), said step of initializing further including the steps of:
 - 30

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scanning the communication system for a
synchronization signal from another node of equal or
higher priority;

5 synchronizing said first node to said another
node if located; and

 sending a synchronization signal from said
first node if said another node is not located.

5. Method according to claim 2, wherein said
first node is assigned said third priority (STA), said
10 step of initializing further including the steps of:

 scanning the communication system for a
synchronization signal from another node of higher
priority;

15 synchronizing said first node to said another
node if said another node is located; and

 signalling that a synchronization signal was
not detected if said another node is not located.

6. Method according to claim 2, further
comprising the step of:

20 dynamically reconfiguring the communication
system as nodes enter or depart communication range
with remaining nodes of the communication system.

7. Method according to claim 2, wherein said
first node is assigned said second priority (ALTSTA),
25 said step of searching the communication system further
including the steps of:

 scanning the communication system for a
synchronization signal from another node of said first
or said second priority;

30 continuing normal operation if said
synchronization signal is not detected; and

 synchronizing to a node of said first
priority if a synchronization signal from a node of
said first priority is detected.

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8. Method according to claim 2, wherein said first node is assigned said second priority (ALTSTA), said step of searching the communication system further including the steps of:

5 scanning the communication system for a synchronization signal from another node of said first or said second priority;

continuing normal operation if said synchronization signal is not detected; and

10 synchronizing to a node of said second priority if a synchronization signal from a node of said second priority is detected and if a synchronization signal from a node of said first priority is not detected.

15 9. Method according to claim 1, wherein said step of synchronizing the nodes to said second node further includes the steps of:

20 sending a synchronization signal from said first node to each of said nodes, said synchronization signal indicating a hop number of said second node.

10. Method according to claim 1, wherein said step of synchronizing further includes a step of:

25 broadcasting a resynchronization request to inform all nodes of the communication system to synchronize to said second node.

11. A communication system comprising at least two nodes, each of said nodes being assigned at least one of three different hierarchical designations such that at any given time, a node used to control
30 synchronization of the communication system can be switched from a first one of said nodes to a second one of said nodes to provide a distributed synchronization control system.

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12. A communication system according to claim 11, wherein said communication system is a peer-to-peer network.

5 13. A communication system according to claim 11, wherein said communication system is an ad hoc network.

14. A communication system according to claim 11, wherein said communication system is a server based network.

10 15. Method for controlling frequency hopping communication among plural nodes in a communication system comprising the steps of:

transmitting a synchronization signal from a first node during a predetermined contention-free synchronization period; and

15 synchronizing frequency hopping of at least a second node to said first node via said synchronization signal.

16. Method according to claim 15, wherein said step of transmitting further includes a step of:

20 transmitting said synchronization signal for a period sufficient for said plural nodes to scan all frequencies of said frequency hopping communication system.

25 17. A method according to claim 15, wherein said step of synchronizing frequency hopping of at least a second node to said first node further includes steps of:

30 scanning all frequencies of a frequency hopping sequence to detect said synchronization signal; and

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locking a frequency of said second node to said synchronization signal upon detection of said synchronization signal by said second node.

5 18. Method according to claim 15, wherein said step of transmitting further includes a step of:
 transmitting a synchronization signal which includes a fixed pattern preamble and a data packet for identifying a transmission frequency.

10 19. Method according to claim 15, wherein said step of transmitting further includes a step of:
 transmitting a synchronization signal which includes synchronization information for aligning a hop period.

15 20. Method according to claim 19, wherein said step of transmitting further includes a step of:
 delaying the transmission of said synchronization information for a predetermined period of time to account for frequency drift within a hop period.

20 21. Method according to claim 15, wherein said communication system includes at least two nodes, each of said nodes being assigned at least one of three different hierarchical designations such that at any given time, a node used to control synchronization of
25 the communication system can be switched from a first one of said nodes to a second one of said nodes, and wherein said method further includes a step of:
 searching for synchronization signals transmitted by other nodes of said communication system
30 prior to said step of transmitting.

22. Method for controlling a first node of a communication system having a plurality of nodes using

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frequency hopped radio signals, each node of said communication system being assigned a hierarchical designation representing a priority of a node to control synchronization of the frequency hopped radio signals, said method comprising the steps of:

(a) when said first node is of a first priority, sending a synchronization signal from said node without searching for other nodes of said first priority;

(b) when said first node is of a second priority, scanning the communication system for a synchronization signal from another node of equal or higher priority, synchronizing said first node to said another node if located, and sending a synchronization signal from said first node if said another node is not located; and

(c) when said first node is of a third priority, scanning the communication system for a synchronization signal from another node of a higher priority, synchronizing said first node to said another node if said another node is located, and signalling that a synchronization signal was not detected if said another node is not located.

23. Method according to claim 22, further comprising the step of:

dynamically reconfiguring said communication system to synchronize all nodes within communication range of said first node with said first node.

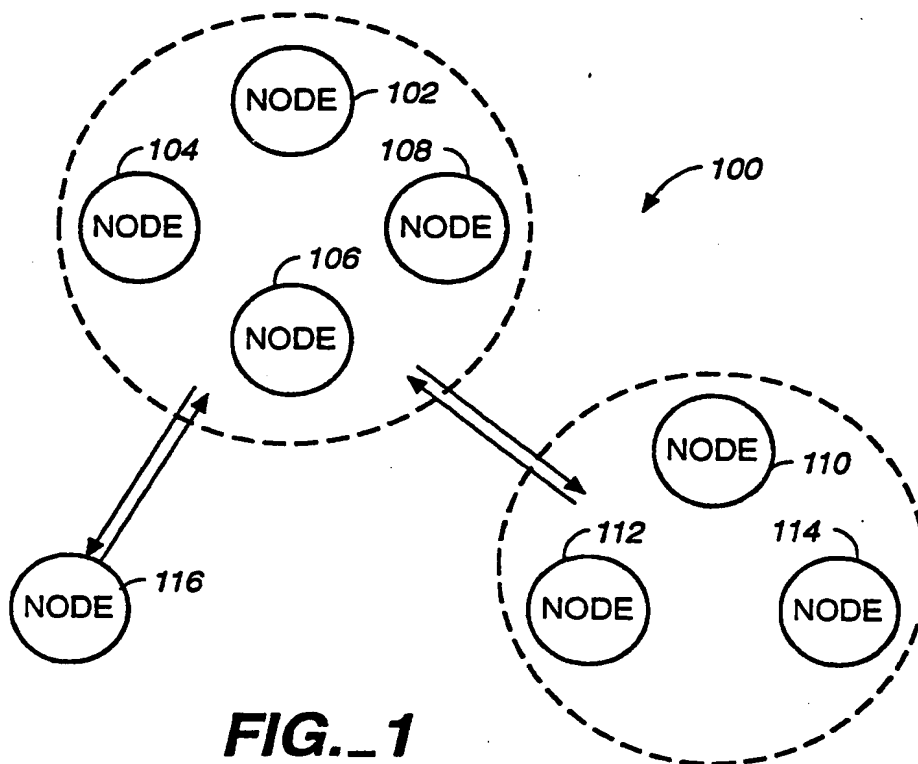
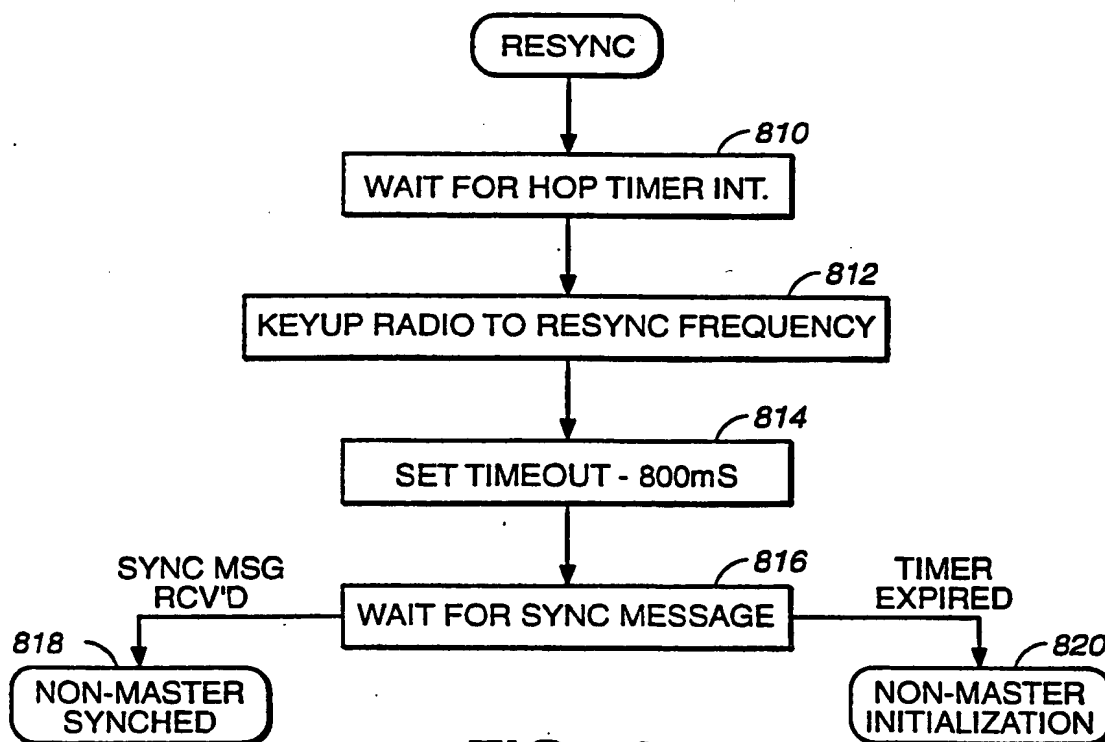
24. Method for controlling communication of frequency hopped radio signals among a plurality of nodes in a communication system each of said nodes being assigned a hierarchical designation to control synchronization of the communication system, comprising the steps of:

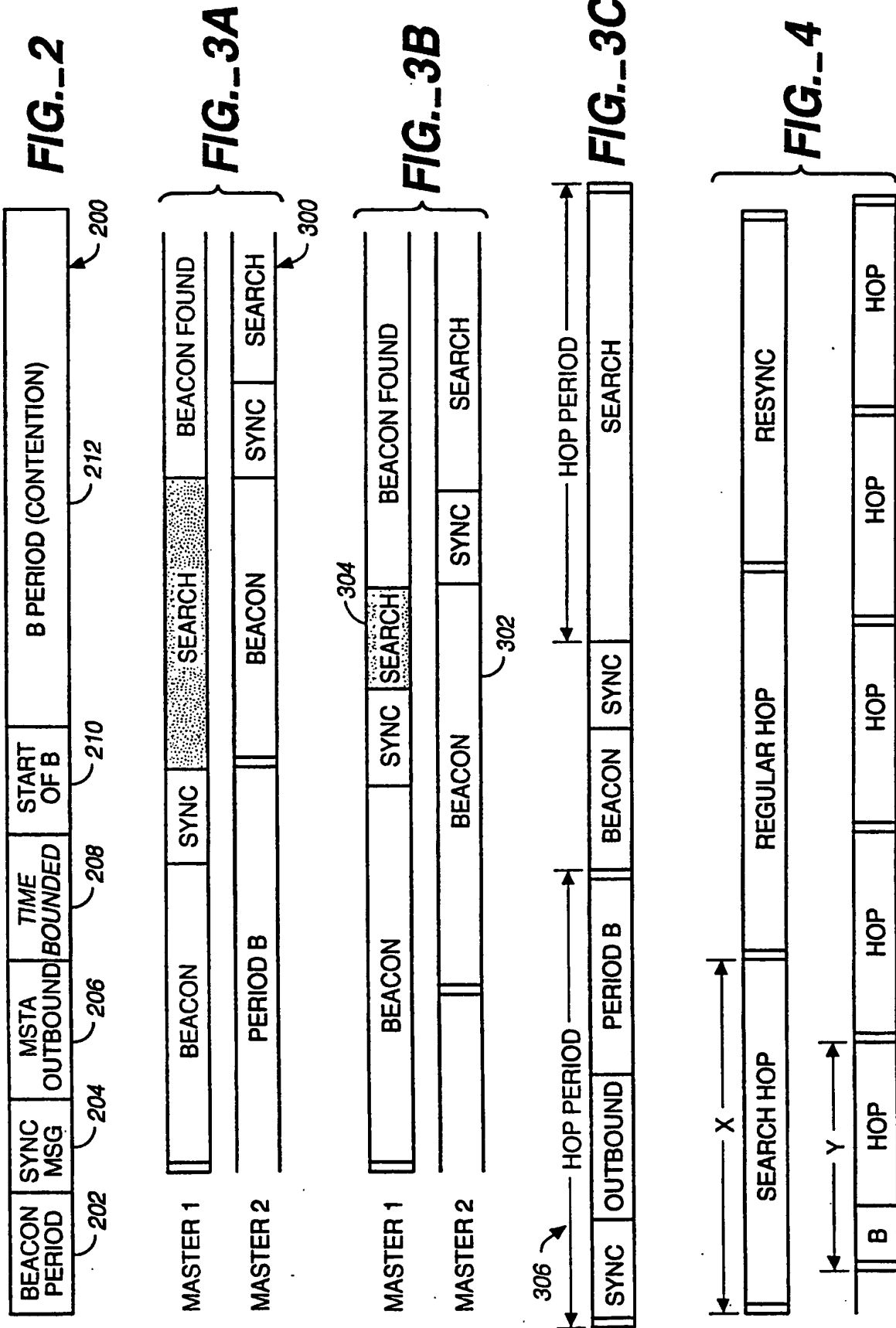
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initializing the communication system by
synchronizing the plurality of nodes to a first node of
said plurality of nodes; and

- 5 dynamically reconfiguring the communication
system when nodes enter or depart communication range
with said first node, said dynamic reconfiguration
being based on said hierarchical designations.

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**FIG. 1****FIG. 8**



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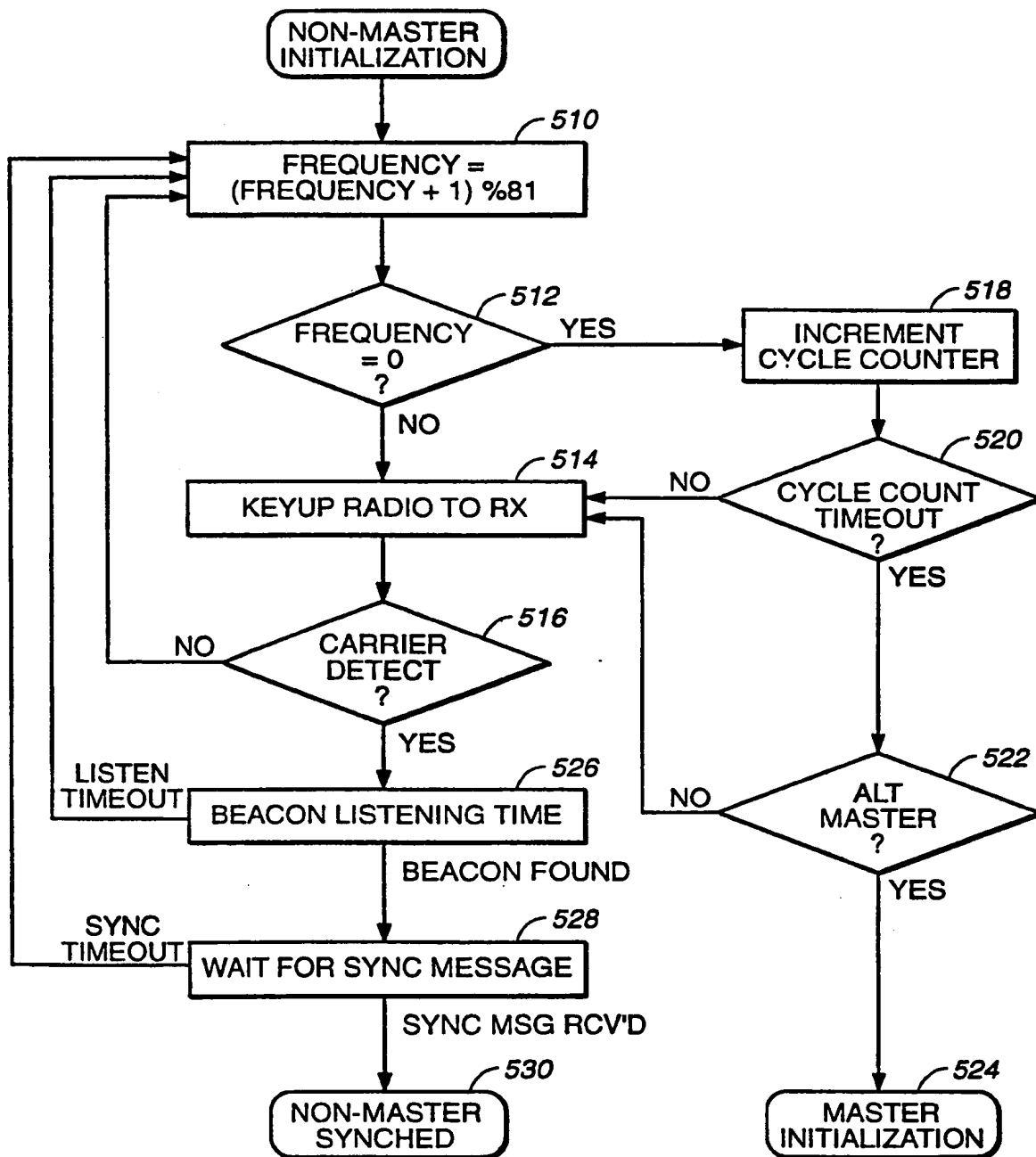
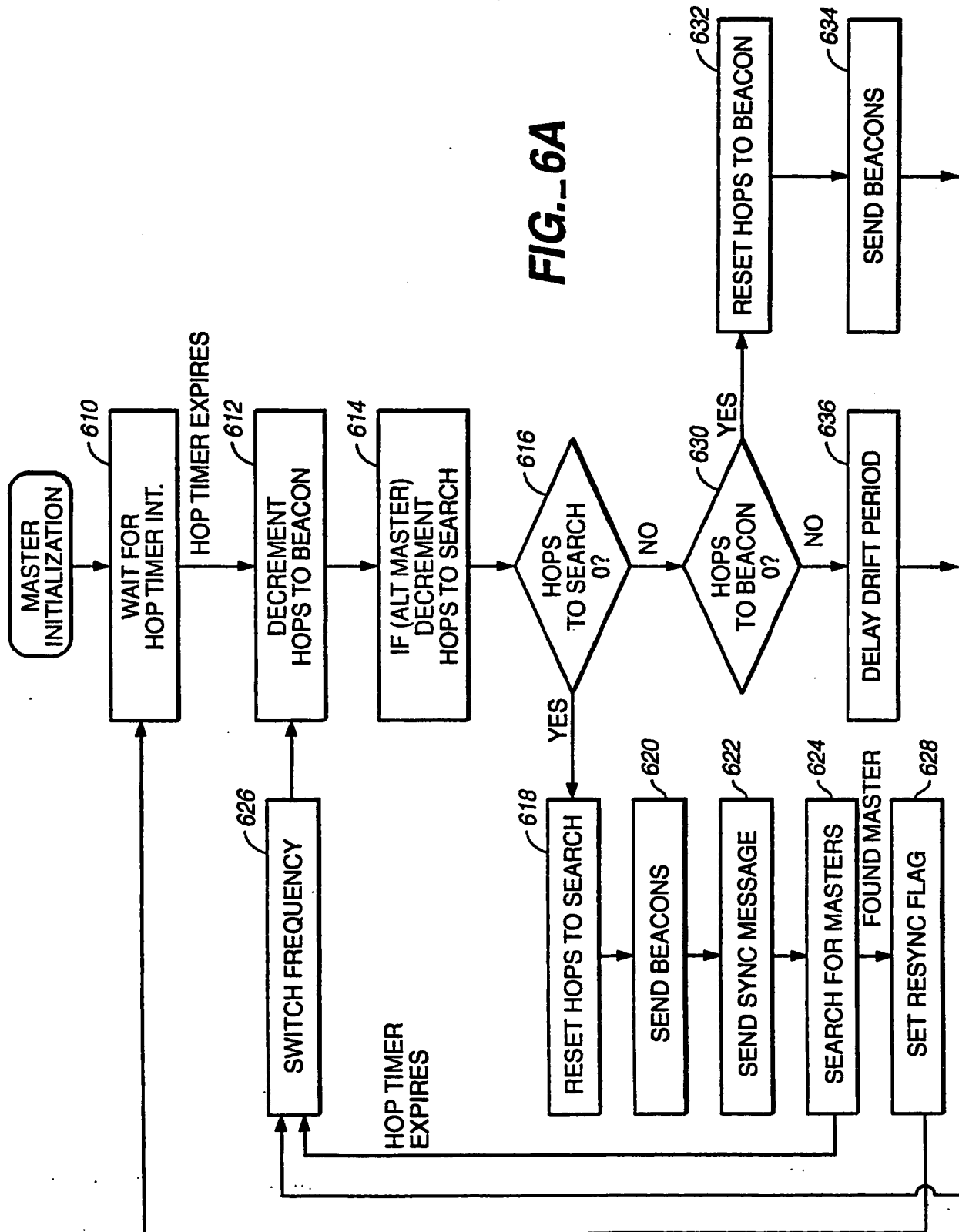
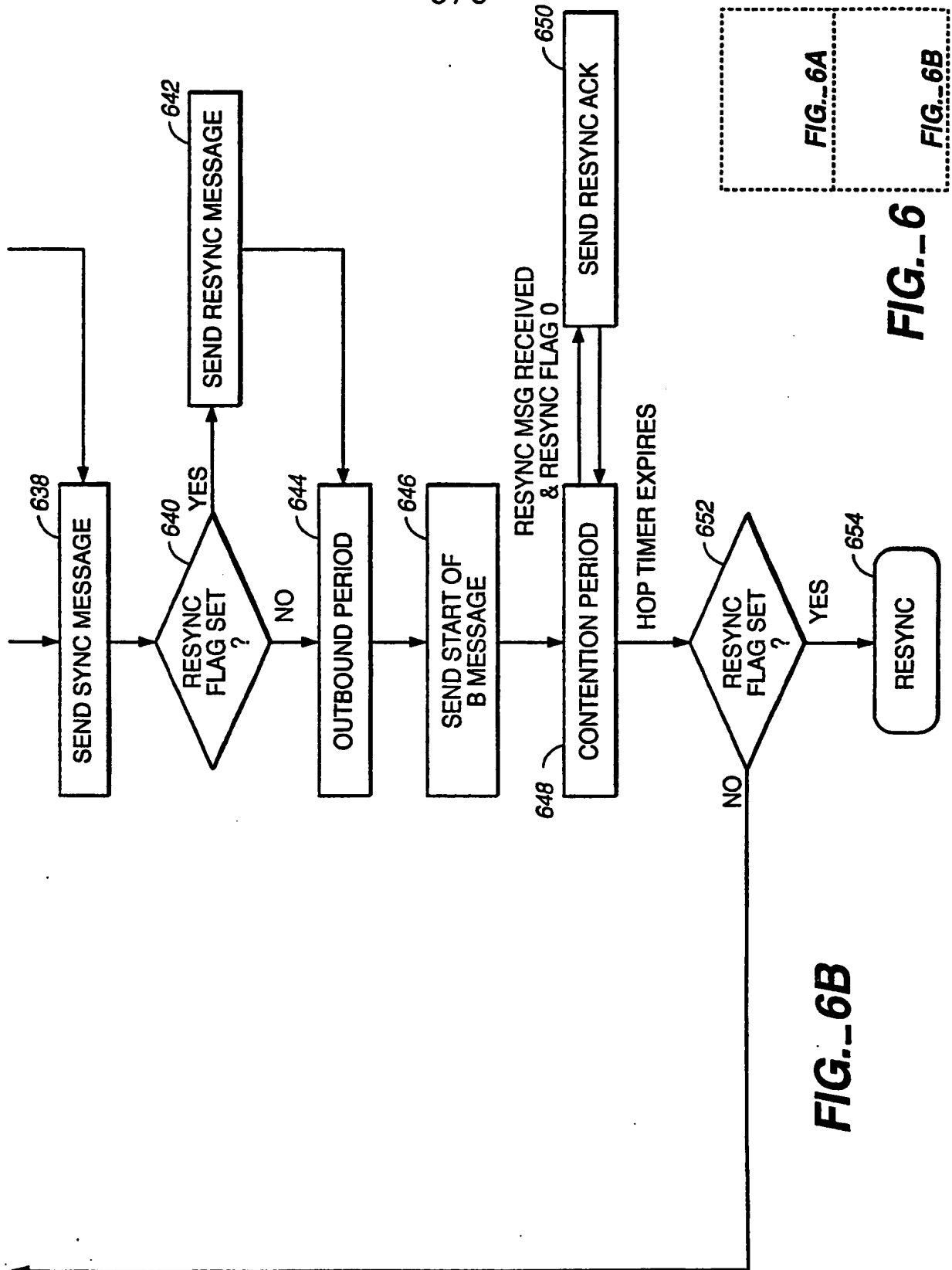
**FIG. 5**

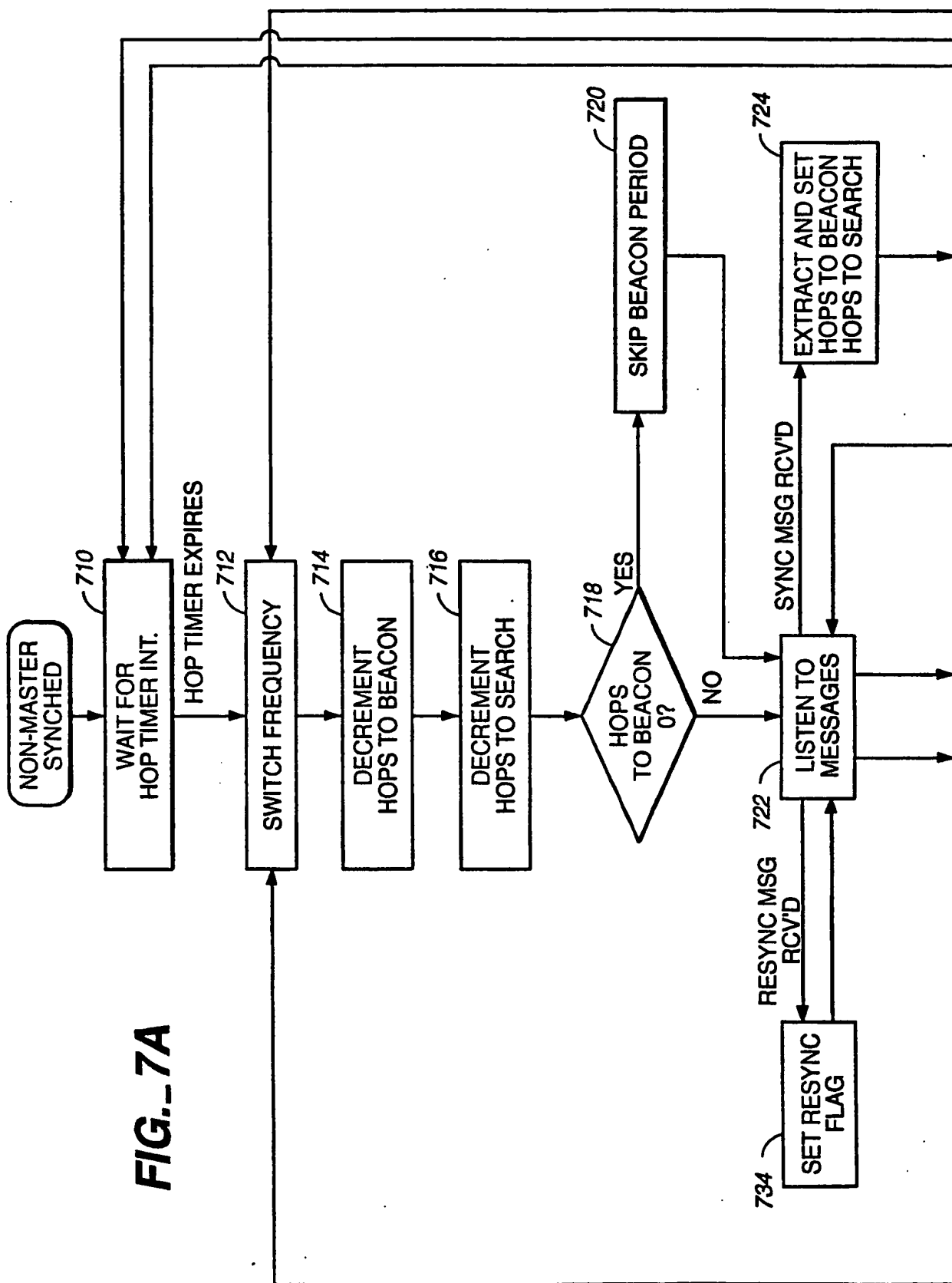
FIG. 6A



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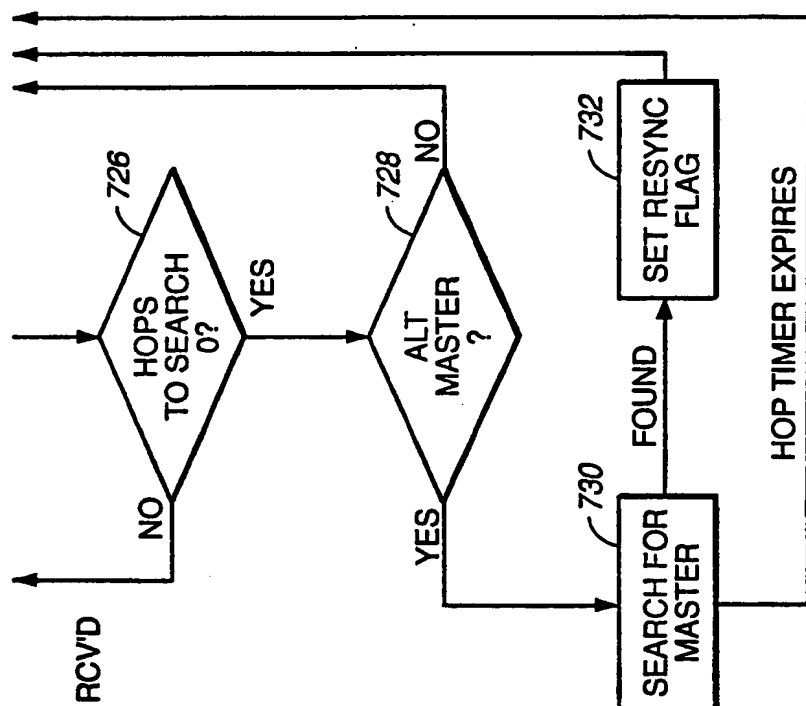


FIG. 7A

FIG. 7B

FIG. 7

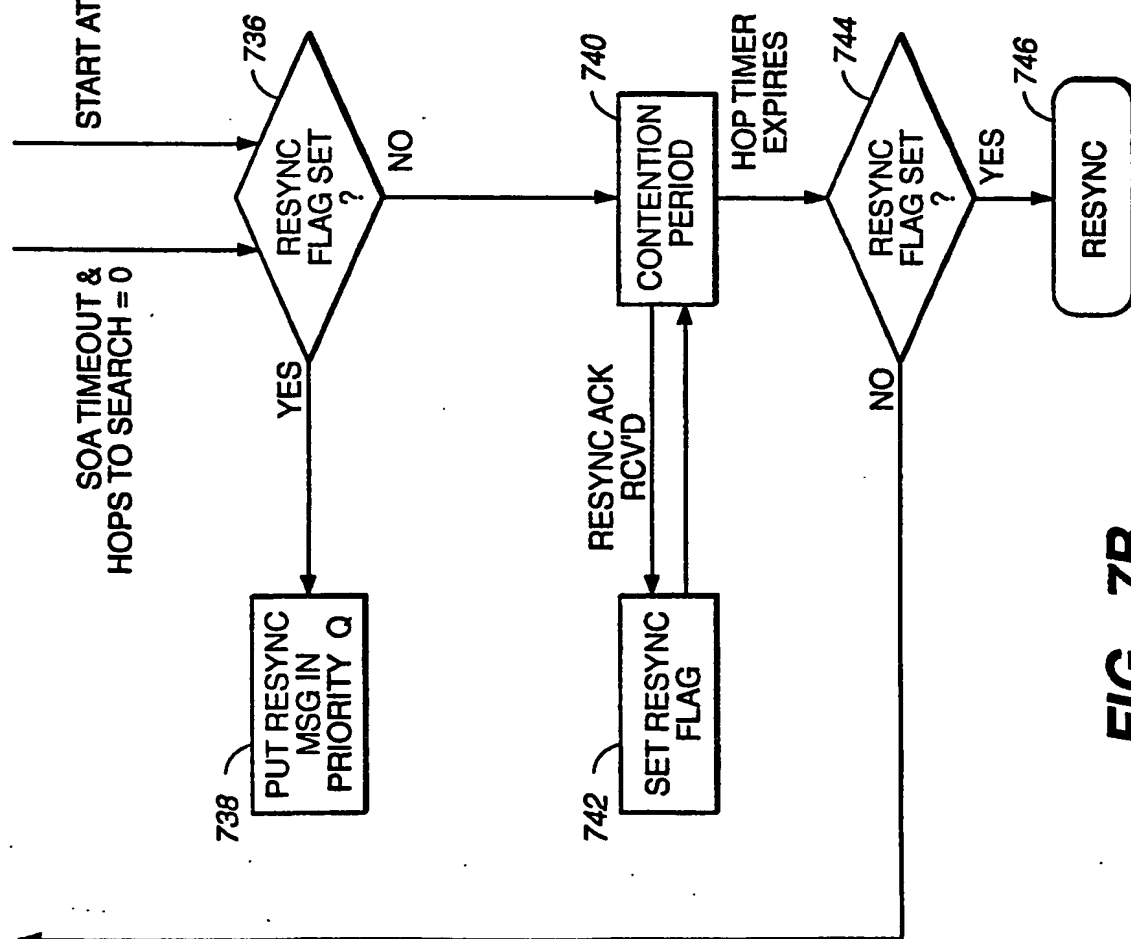
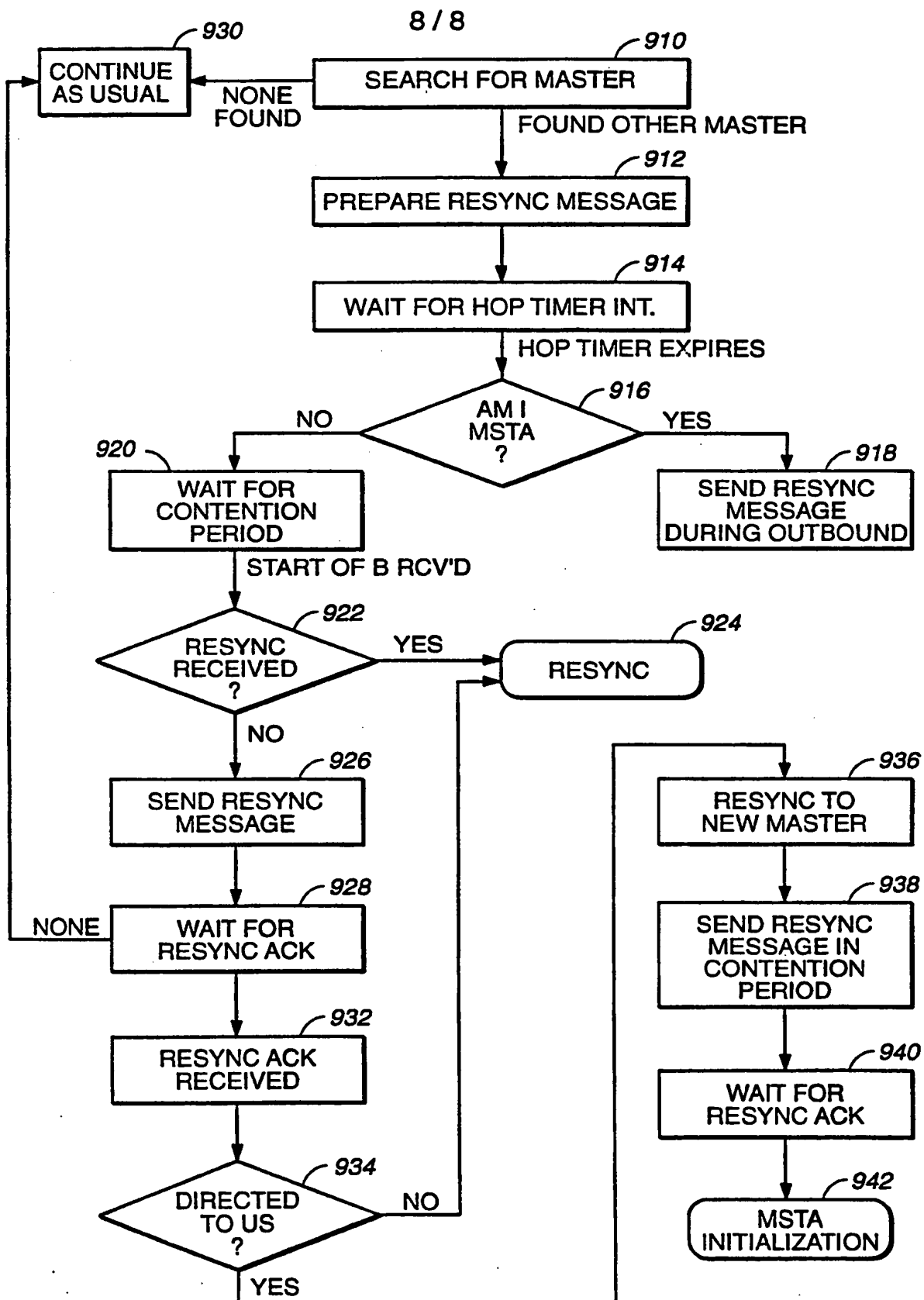


FIG. 7B

**FIG. 9****SUBSTITUTE SHEET (RULE 26)**

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/02542

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :HO4B 1/713

US CL :375/202

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : Please See Extra Sheet.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 4,554,668 (DEMAN ET AL.) 19 NOVEMBER 1985, SEE ENTIRE DOCUMENT.	15-21
X	US, A, 4,558,453 (MIMKEN) 10 DECEMBER 1985, SEE ENTIRE DOCUMENT.	15-21
X	US, A, 4,677,617 (O'CONNOR ET AL.) 30 JUNE 1987, SEE ENTIRE DOCUMENT.	15-21
X	US, A, 4,850,036 (SMITH) 18 JULY 1989, SEE ENTIRE DOCUMENT.	15-21
X	US, A, 5,121,408 (CAI ET AL.) 09 JUNE 1992, SEE ENTIRE DOCUMENT.	15-21

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:	*T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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E earlier document published on or after the international filing date	*Y*	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Z*	document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means		
P document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

06 APRIL 1995

Date of mailing of the international search report

22 MAY 1995

Name and mailing address of the ISA/US
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Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/02542

B. FIELDS SEARCHED

Minimum documentation searched
Classification System: U.S.

375/202

375/1, 107; 380/34, 48; 395/200;

370/85.1, 85.2, 85.3, 85.4, 85.6.